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Learning to Learn

The Art of Doing Science and Engineering

Session 1: Orientation

Purpose of the course

Prepare you for your technical future

Much technical content is covered

- but that material is review, not the point of the course

Style of thinking is the center of the course

- examine, criticize and display styles of thinking
- complement existing courses, what you need to know

Concerned with educating, not training you

Dilemma

Some things aren't expressed well in words

- Early Greeks (Socrates, Plato) believed anything can be described in words
- Principles of scientific reductionism

Contrast: need for experience

- Gods, truth, justice, arts, beauty, love

Style of thinking is a topic in its own right

First person

Must present first-hand knowledge and experience to be effective in this course

- breaks scientific taboo, analysis is usually impersonal
- nevertheless the most effective form for this course
- goal is to change listeners' minds, ways of thinking

Unfortunately can sound like "bragging"

- "Hamming on Hamming"
- apologies for that

Coaching

Role is that of “coach”

- students must still do the work themselves, mull things over, compare to own experiences, discuss
- make some points part of your way of doing things

Style: comparison to painting

- fundamentals, apprenticeship, mastery, forge style out of combined influences and native ability

Education versus training

Education is what, when, why to do things

Training is how to do it

Either one without other is not of much use

Focus on future

Examine likely state of Science

- at time of your greatest contributions, say year 2020

Since Newton's time, scientific / engineering knowledge has doubled every 17 years

- various metrics, e.g. publication count, size of libraries
- number of people employed in technical jobs
- growth rate of scientists: currently almost 90% of all scientists who ever lived are now alive!

“Back of the envelope” calculations are important

Goal: verify your thoughts quantitatively

- it is very significant to consider that aggregate sum of all human knowledge increases exponentially
- how can we test such ideas?

Example comparison of two assumptions

I. knowledge doubles every 17 years

II. 90% of scientists who ever lived are now alive

Exponential change for amount of human knowledge

I. Assume knowledge doubles every 17 years

- Equation for first assumption becomes

$$y(t) = a \cdot e^{bt}$$

$$\tfrac{1}{2} = \frac{\int_{\infty}^{t-17} ka \cdot e^{bt} dt}{\int_{\infty}^{t} ka \cdot e^{bt} dt} = \frac{\left(ka/b\right) e^{b(t-17)}}{\left(ka/b\right) e^{bt}} = e^{-17b}$$

$$b = -\frac{\ln\left(\frac{1}{2}\right)}{17} = -0.04077$$

$$\tfrac{1}{2} = e^{bD}$$

Exponential change for number of scientists

II. Assume growth of knowledge proportional to number of scientists at any time *t*, doubling period D

- Assume working lifetime of scientist L = 55 years
- Equ … comes

$$\frac{9}{10} = 1 - e^{bL} = 1 - \left(\tfrac{1}{2}\right)^{L/D}$$

$$\left(\tfrac{1}{2}\right)^{L/D} = \frac{1}{10}$$

$$\frac{L}{D} = \frac{\log(10)}{\log(2)} = \frac{1}{0.30103} = 3.3219\ldots$$

Validating the two assumptions against each other

- Using D=17 years from assumption I,

$$D \times \left(\frac{L}{D} \right) = 17\,years \times 3.3219 = 56.47\,years$$

- which is a good match to assumption of 55 years

Back of envelope computations thus show that assumptions are reasonably compatible

- Also note that these relationships hold for all time, if assumptions remain valid

Knowledge increase over time

X years	17	27	34	39	44	48	51
Y factor increase	2	3	4	5	6	7	8

Knowledge obsolescence over time

15-year half life

- in 15 years, half of what you have learned will be technically obsolete
- success in your chosen area may make your scientific and engineering knowledge irrelevant
- Hamming example: transistors, vacuum tubes

Dealing with technological change

How to cope?

- concentrate on fundamentals
- develop ability to learn new fields of knowledge

What is fundamental?

- topic has lasted a long time
- fundamentals can be used to derive remainder of field

Science versus engineering

Glib descriptions:

- In science, if you know what you are doing, you should not be doing it
- In engineering, if you do not know what you are doing, you should not be doing it

In actuality:

all engineering involves creativity, and all science involves some practical engineering

Role of history

Often used as long-term guide

- some believe it repeats, others believe the opposite!

Best predictions are based on understanding fundamental forces involved

- Often it is not physical limitations controlling progress
- Human-made laws, habits, organizational rules, regulations, personal egos, inertia can dominate

History is bunk? (Henry Ford)

History is seldom reported accurately

- no two reports of what happened at Los Alamos during WWII seem to agree
- pace of progress seems to disconnect the technological future from the past

Apparent contradictions in historical works

- past determined by big trends, bigger than individuals
- future has great possibilities for individual change

Handling contradictions of a historical perspective

Can cope at least four ways:

1. You can simply ignore it.
2. You can admit the contraction.
3. Decide that past was less deterministic, with individuals able to make large contributions.
4. Decide that future is less open ended than desired, with less choice than there appears to be.

Drunken sailor progress

Well-known relationship

- random walk from starting point traverses average distance proportional to <u>square root of n steps</u>
- random walk towards a pretty girl traverses average distance proportional to <u>n steps</u> (much! farther)
- Moral: having a goal makes a big difference

Thus having a vision of your future is critical

- Accuracy of having the precisely correct goal at every step along the way is definitely secondary

Developing vision of future

Devoted 10% of time (Friday afternoons) to trying to understand future of computing

Three key questions (corresponding fields)

- What is feasible? (Science)
- What is likely to happen? (Engineering)
- What is desirable to happen? (Ethics, morals, values)

Computers will dominate your technical future

Many advantages over humans

- Economics: far cheaper, getting more so
- Speed: far, far faster
- Accuracy: far more accurate (precise)
- Reliability: far ahead (often built-in error correction)
- Rapidity of control: makes modern aircraft feasible
- Freedom from boredom: overwhelming advantage
- Ease of training, hostile environments, personnel…

Also a religious course

With apparently one life to live on this earth, you ought to try to make significant contributions to humanity rather than just getting along through life comfortably.

Choice of goals is yours, but absence is mere existence. Socrates (469-399 BC) said

- "The unexamined life is not worth living."